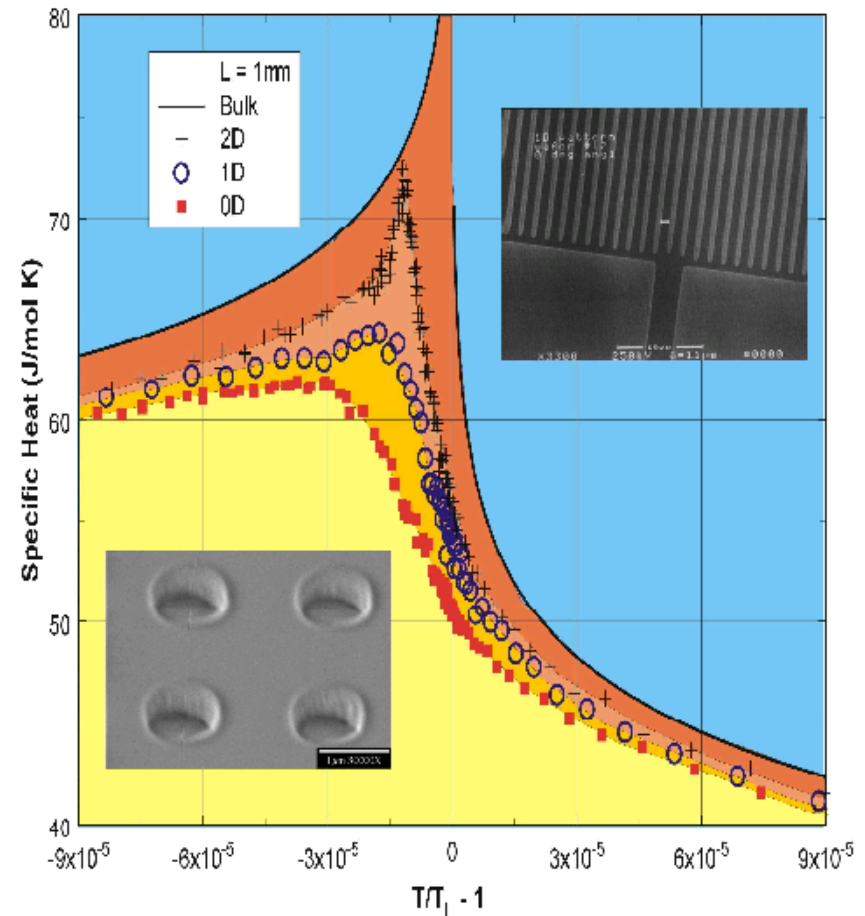


# Dimensionality and Weak-Link Effects at the Superfluid Transition of Helium-4

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Our world is three-dimensional. However, we walk and write on two-dimensional surfaces. Sometimes, such as when traveling through a tunnel, we limit ourselves to motion in one dimension. The role of dimensionality is fundamental in science. It is particularly important at a phase transformation similar to the melting of ice. What we have done recently is to explore, for the first time, the role of dimensionality at a phase transformation which is especially sensitive to space limitations: the normal to superfluid transition in helium. The difference in specific heats of helium confined to 3, 2, 1, 0 dimensions is quite remarkable. As can be seen in the figure, the shape, position and “strength” of the transition are all affected. These studies contribute to the understanding of the role of dimensionality in many other similar systems.

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Specific heat of helium within ~0.01% of the superfluid transition. As one progresses from the top curve, to the bottom data one goes from 3 to 2 to 1 to 0 dimensions.

The figure shows the specific heat of helium in the immediate neighborhood of the superfluid transition. The solid line is for bulk (3D) helium. The data are for confinement to planes (2D), channels (1D), and boxes (0D). The dimensionality refers to the number of directions in which fluctuations are allowed to take place (this is clearly not the same type of transition as the first order transition of ice melting). The insets are micrographs of boxes and channels which are formed lithographically on a silicon wafer. The final structure to form a cell is obtained by bonding another wafer to “cap” the structure shown in the micrographs. The bonding of the top wafer results in confinement of  $1\mu\text{m} \times \infty \times \infty$  (not shown),  $1\mu\text{m} \times 1\mu\text{m} \times \infty$  and  $1\mu\text{m} \times 1\mu\text{m} \times 1\mu\text{m}$ . The “ $\infty$ ” here means  $\sim\text{cm}$  length. In particular for the boxes, the “capping” is done with a wafer which has 18 nm “fill” channels through which the helium is introduced. The role of these small channels (18nm high,  $1\mu\text{m}$  long and  $1\mu\text{m}$  wide) --which may be thought of as “weak links”-- is still being explored.

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## Education

Most recently two undergraduate students, through summer appointments, have contributed to this research, Luke Hodur and Jake Davies. They are physics majors in the department. The principal work in our research is performed by three graduate students, Mark Kimball, Kevin Mooney and Manuel Diaz-Avila. Mark is currently writing his PhD thesis. Kevin and Manuel will do so next year. All graduate students have presented papers on their work at national and international meetings. Mark in particular has given two invited talks: at the Quantum Fluids and Solids conference in Konstanz (2001), and the Low Temperature conference in Hiroshima (2002). Mark and Manuel have received a special dissertation fellowship from the College of Arts and Sciences.

## Societal Impact

Our work will lead to a greater understanding of the behavior of small systems. This will impact most directly the field of magnetism and its relevance in magnetic storage devices as well as the development of magnetic semiconductor devices for new generations of computer electronics.

Also, the technology of direct wafer bonding, which we have developed to construct small enclosures, is relevant to very small scale fluid flow with applications to chemical and medical research. It also has direct relevance to the semiconductor technology of silicon-on-insulator electronics.